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Chapter

Characterization of Printed Podal Vivaldi Antenna (8–18 GHz) on RT Duroid with Single and Double Cavity

P. Venu Madhav and M. Siva Ganga Prasad

Abstract

In today's modern communication systems, miniaturized and lightweight subsystems covering broad bandwidth are in much demand as they lead to realization of very compact and lightweight systems. A printed podal Vivaldi antenna with single as well as double cavities fed with strip line transmission line and operating from X band to K_U band (8–18 GHz) is proposed. The comparison of antenna performance for single cavity and double cavity is also reported. Using double cavity, the miniaturization of antenna is possible as compared to single cavity Vivaldi antenna. The antenna is first designed using conventional theoretical approaches. Later, it is simulated using a 3D EM simulation software, CST Microwave Studio^{TM}. The optimal value for taper length is 6.86455 cm and cavity diameter is 1.582 cm. Finally, the design is physically fabricated using PCB technology for carrying out practical measurement. The antenna's input impedance characteristic is measured in the form of S-parameter and VSWR using Vector network analyzer. VSWR less than 3:1 is achieved over the band from 8 to 18 GHz. The radiation pattern measurements are carried out in anechoic chamber. The proposed Vivaldi antenna is used for digital data transmission via satellites and for voice/audio transmissions.

Keywords: Vivaldi, broadband antenna, microstrip, VSWR, characteristic impedance

1. Introduction

The recent explosion in information technology and wireless communications has created many opportunities for enhancing the performance of existing signal transmission and processing systems and has provided a strong motivation for developing novel antenna structure for systems that require wider bandwidths and higher data transmission.

In today's modern communication systems, miniaturized and lightweight subsystems covering broad bandwidth are in much demand as they lead to realization of very compact and lightweight systems. To accomplish this, small and lightweight antennas which cover wide bandwidth without much degradation in their performance are required to be designed and realized. As antenna

dimensions are governed by wavelength of operating frequency, antenna miniaturization is a challenging and difficult task. Planar/printed antennas offer good solutions for the above class of problem. Vivaldi antennas are preferable in many applications due to high gain, simple structure and easy fabrication. They are mostly used in ultra-wideband and broadband applications. Printed antennas are being increasingly used as they are low profile and can be integrated on any printed circuit easily.

Most of the wireless communication systems suffer from co-channel interference and multipath effects. The co channel interference and multipath effects are addressed by using horn antennas that are placed in LOS, but these antennas are too bulky to be integrated with the rest of the wireless systems and suffer high cost of fabrication. For military and commercial applications wideband width antennas with high gain are preferred and Vivaldi antenna or planar tapered slot antenna (TSA) are better choice. As these antennas are support for multifunction communication applications because of their consistent impedance matching over a very broad operating frequency range, stable directional patterns, low profile and planar structures.

The Vivaldi and TSA's offer broadband operation, with low sidelobes but moderate gain.

Problem definition: The objective is to design the single cavity and double cavity Vivaldi antenna operating from 8 to 18 GHz frequency to achieve VSWR less than 3:1 and comparison of antenna performance for single cavity and double cavity Vivaldi antenna.

2. Vivaldi antenna

A Vivaldi antenna gives significant advantages of efficiency, high gain, wide bandwidth and simple geometry. The Vivaldi antenna, having an exponentially tapered slot profile, is a type of tapered slot antenna (TSA). Lewis et al. [1] introduced tapered slot antenna as a broadband strip line array element capable of multi octave bandwidths in his study in 1974. Vivaldi antenna, is an exponentially tapered slot antenna, was originated by Gibson [2]. These antennas operate in the frequency range from below 2 to above 40 GHz and offer significant gain and linear polarization.

Yngvesson et al. [3] compared three different TSAs, linearly tapered slot antenna (LTSA), constant width slot antenna (CWSA) and Gibson's exponentially tapered slot antenna, Vivaldi antenna.

Gazit [4] proposed two important changes to the traditional Vivaldi design. The use of a low dielectric substrate (cu clad, ε = 2.45) instead of alumina and an antipodal slot line transition. This type of transition offers relatively wider bandwidth but, antipodal slot line transition has high cross polarization problem.

3. Principle of operation

The Vivaldi antenna belongs to travelling wave antennas. The principle of operation of the surface wave antennas can be divided into two sections: propagating section and radiating section.

3.1 Vivaldi antenna design

The design guidelines for a Vivaldi antenna are the following:

1. the flare height and length should be greater or equal to half wavelength at minimum operating frequency;

2. the taper factor influences the impedance matching; and

3. the cavity diameter should be equal to 0.2 λ times the minimum operating frequency.

The separation between the conductors is smaller than one-half free space wavelength ($\lambda_0/2$) [5] and the waves travelling down the curved path along the antenna are tightly bound to the conductors in the propagating section. The energy gets radiated into the air in the radiating section where the slot width is increasing beyond the one-half wavelength. Radiation from high-dielectric substrates is very low and hence for antenna applications significantly low dielectric constant materials are chosen.

Apart from these, the design parameters are as follows:

1. antenna length;

2. antenna width;

3. mouth opening;

4. throat length;

5. edge offset; and

6. backwall offset.

Depending on the dimensions of the transmission line the characteristic impedance is calculated and the vivaldi antenna is printed on both sides of the substrate with a dielectric constant, $\varepsilon_r = 2.2$ and thickness of the substrate is h = 0.508 mm. The length and width of the antenna are optimized.

3.2 Construction

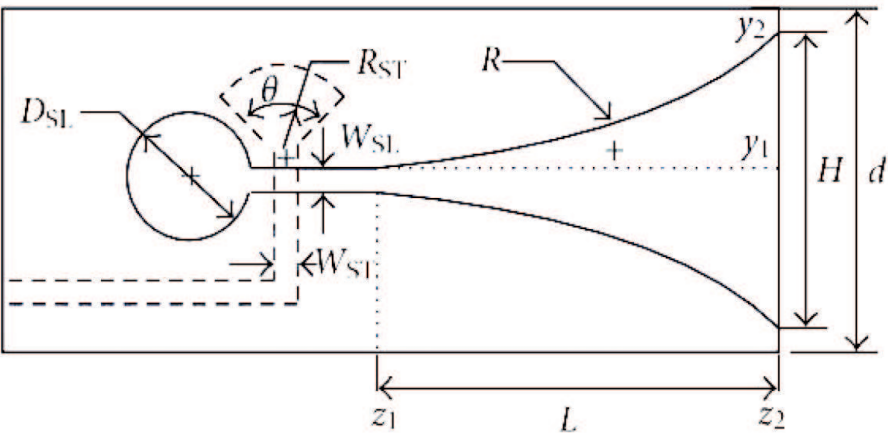From **Figure 1**, the parameters of Vivaldi antenna are described as:

Figure 1.
Vivaldi antenna.

- D_{SL}—diameter of slot line cavity;

- W_{SL}—width of slot line;

- W_{ST}—width of strip line;

- R_{ST}—radius of strip line stub;

- L—length of the taper;

- H—height of the taper;

- R—exponential factor; and

- d—height of the conductor.

The antenna consists of a tapered slot etched onto a thin film of metal. This can do either with or without a dielectric substrate on one side of the film. The tapered slot antennas work over a large frequency bandwidth and produce a symmetrical end-fire beam with appreciable gain and low side lobes. An important step in the design of the antenna is to find suitable feeding techniques for the Vivaldi.

The taper length should be on the order of one wavelength in the lowest working frequency. Besides, the taper length is also dependent on the cavity diameter and antenna length. An increase in the taper length improves the bandwidth.

The taper rate can be defined by an exponential.

$$y \; = \; \pm A e^{Rx} \tag{1}$$

where $A = Sw/2$, $(R=) \dfrac{\ln\left(\frac{a}{Sw}\right)}{La}$ and a is the antenna aperture at L_a, S_w is the slot width at the antenna origin and R is the taper rate.

3.3 Bandwidth consideration

To achieve a wider bandwidth, the following aspects need to be considered:

- the transition from the main input transmission line to the slot line is done for feeding the antenna;

- it is designed for a low reflection coefficient to match the potential of the antenna; and

- the dimensions and shape of the antenna, to obtain the required beam width, side lobes and back lobes, over the operating range of frequencies.

The length and width of the single cavity Vivaldi antenna are 38.5 and 15 mm respectively. **Figure 2(a)** and **(b)** shows the front and back view of simulated design of single cavity Vivaldi antenna which is excited using strip line [6] shown in **Figure 2(c)**.

The double cavity Vivaldi antenna is compared with this single cavity Vivaldi antenna. The size of single cavity antenna is more than the double cavity antenna,
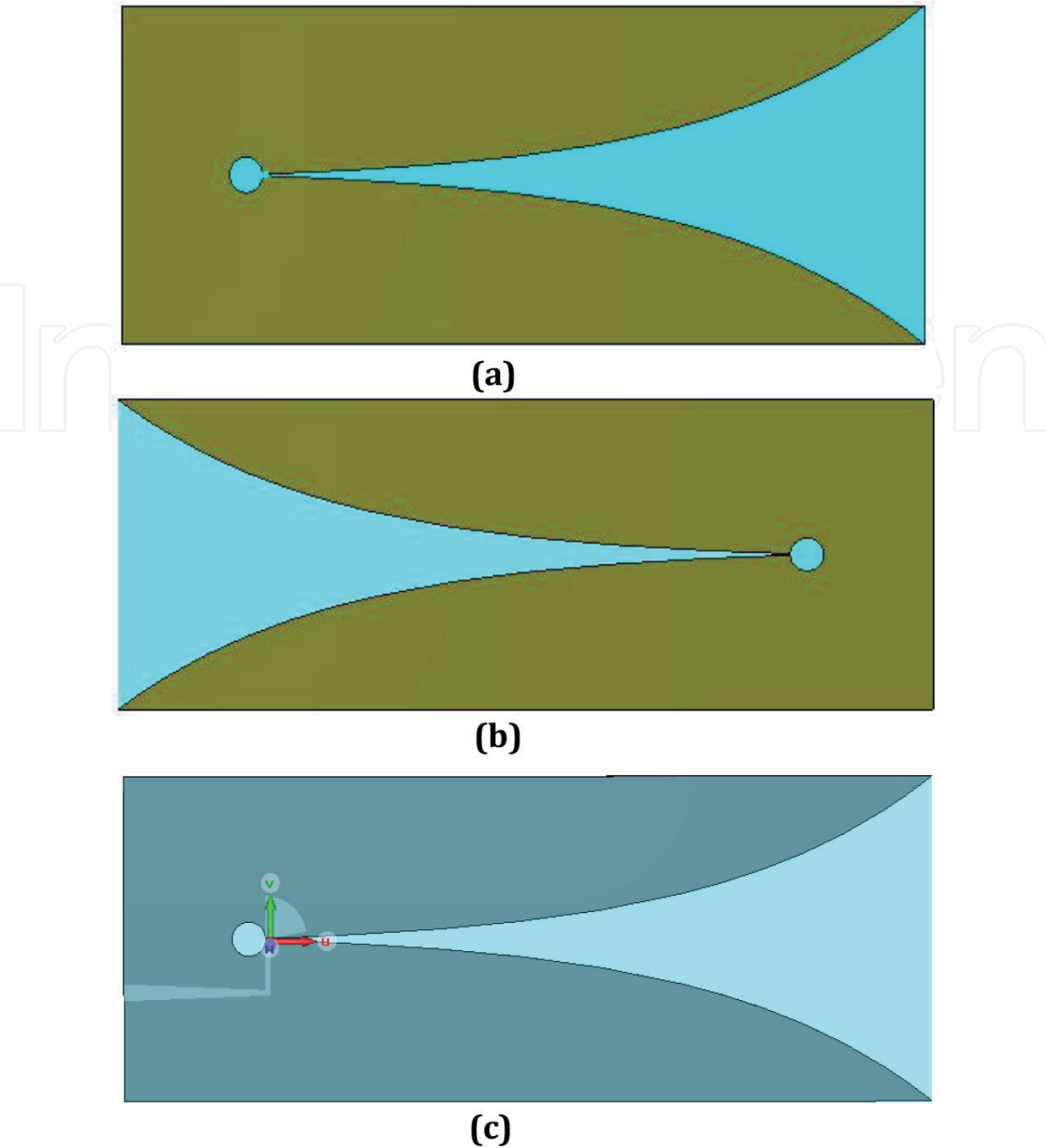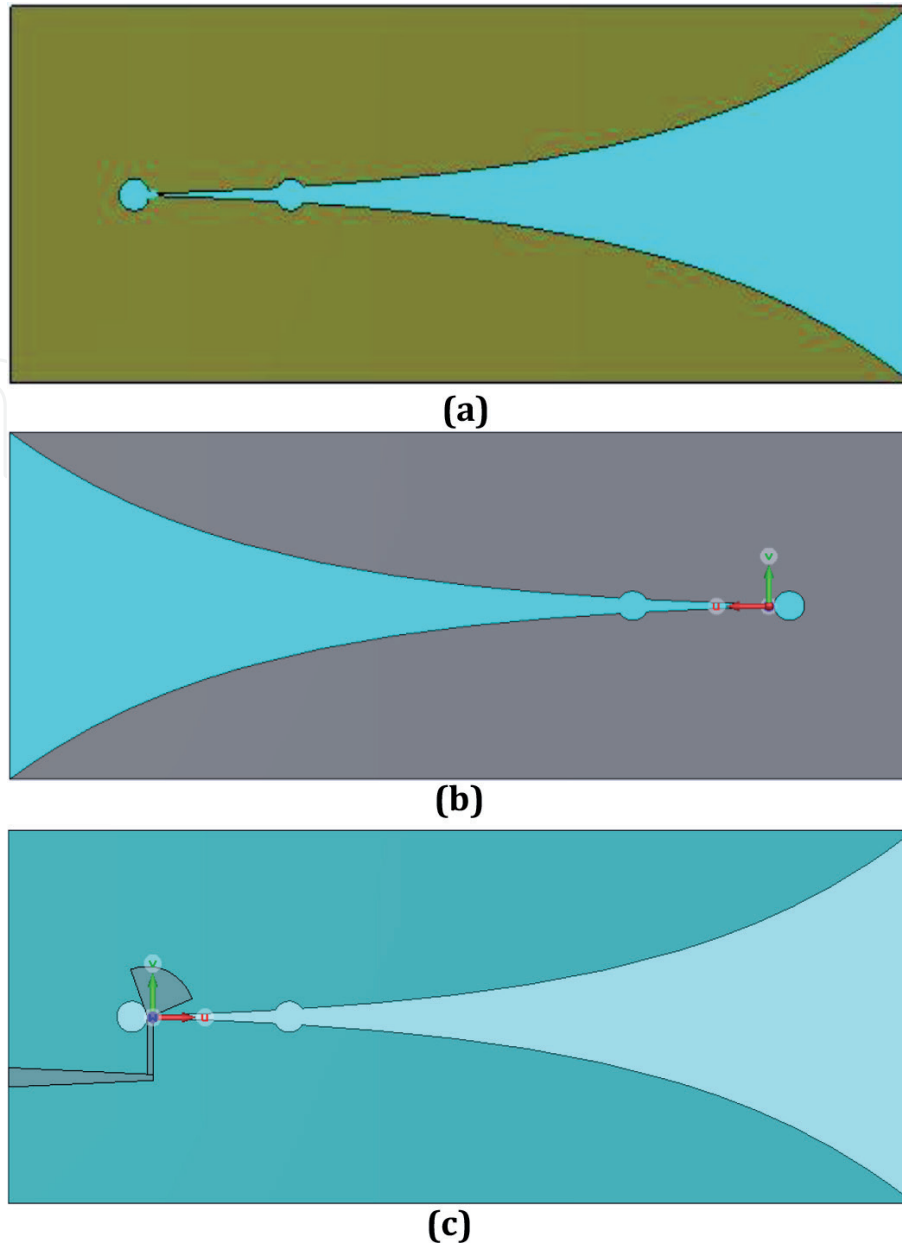
Figure 2.
(a) Front view of single cavity Vivaldi antenna; (b) back view of single cavity Vivaldi antenna; and (c) feeding arrangement of single cavity Vivaldi antenna.

the stub angles of tapered strip line feed also change. The length and width of double cavity Vivaldi antenna are 37.5 and 15 mm respectively. **Figure 3(a)–(c)** shows the front view, back view and feeding arrangement of double cavity Vivaldi antenna.

Parameter values for single cavity antenna is same as double cavity parameter list except some parameters are

stub start angle = 90°
stub angle = 80°
taper length = 6.86455
cavity diameter = 1.582

The VSWR-frequency plot for the Vivaldi antenna without SMA connector seems to have a high VSWR, which means the reflection of power is more and also the reflected wave amplitude is high from frequency 8 to 18 GHz.

Figure 3.
(a) Front view of double cavity Vivaldi antenna; (b) back view of double cavity Vivaldi antenna; and (c) feeding arrangement of double cavity Vivaldi antenna.

To lower the VSWR, a connector is attached to the antenna for the required band of frequencies. **Figure 4(a)** and **(b)** shows the simulated single cavity Vivaldi antenna and double cavity Vivaldi antenna with SMA connector in CST software respectively. The designed SMA connector in CST software is shown in **Figure 5**.

3.4 Fabricated Vivaldi antenna

The single cavity and double cavity [7] Vivaldi antenna operating from 8 to 18 GHz are fabricated individually on the substrate. The two substrates are joined to form a dual layered Vivaldi antenna [8] for both cavities separately. Normally, a FR4 substrate is used. This substrate is also the most commonly used PCB board which is cheap and easily fabricated.

Phase velocity of the propagating surface wave determines radiation performance [9]. Therefore, radiation pattern and performance is dependent upon
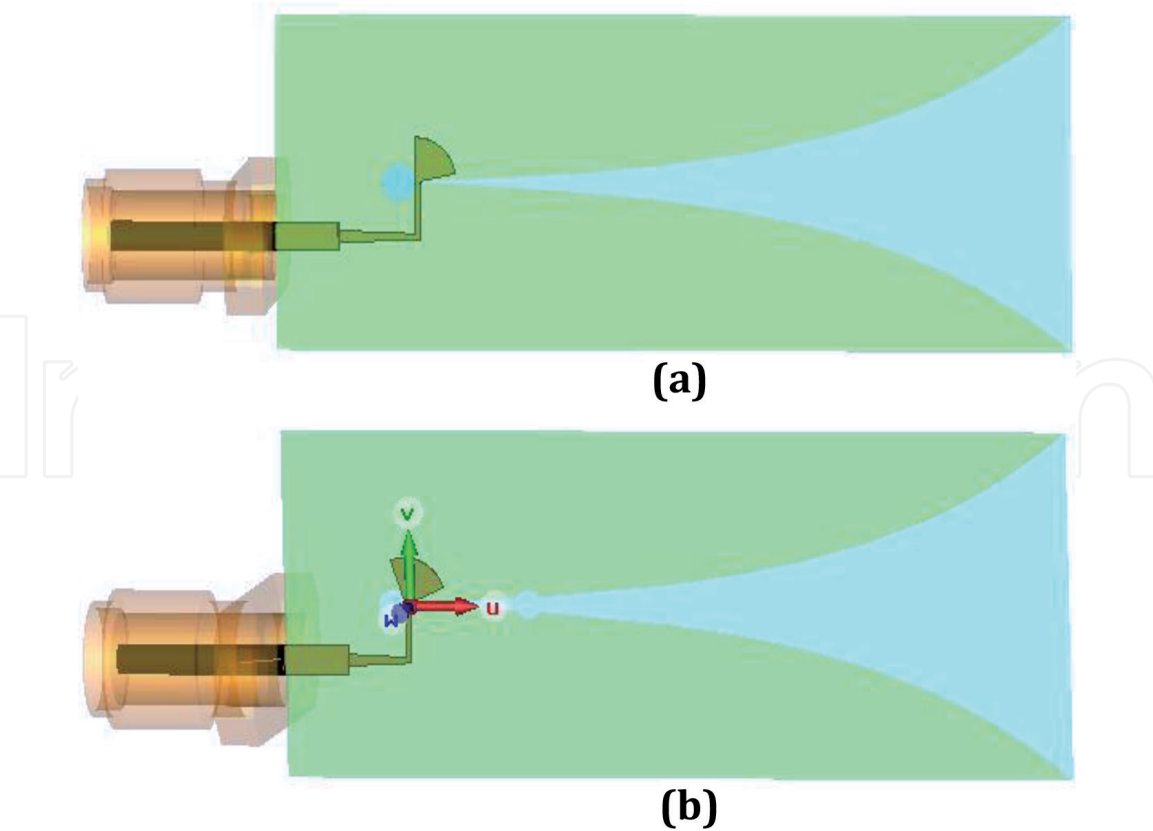
Figure 4.
(a) Single cavity Vivaldi antenna with SMA connector and (b) double cavity Vivaldi antenna with SMA connector.
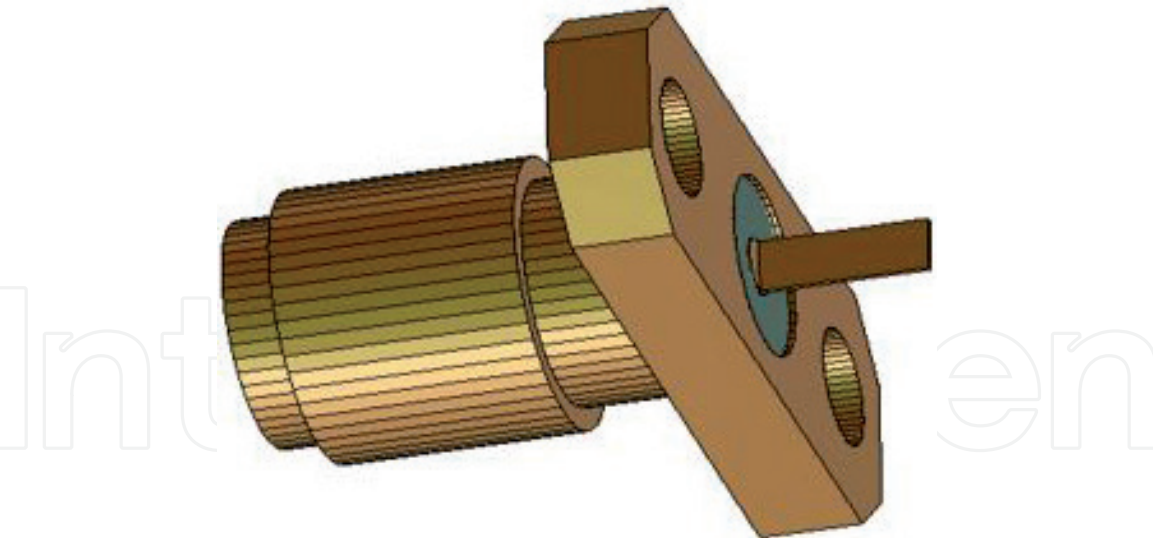
Figure 5.
Design of SMA connector in CST software.

substrate thickness and dielectric constant. The primary effect of the dielectric substrate is the narrowing of the main beam of the antenna. Low dielectric constant substrates maximize the antenna radiation by reducing the dielectric discontinuity at the end of the TSA.

Figure 6(a) and **(b)** shows the fabricated single cavity Vivaldi antenna and double cavity Vivaldi antenna respectively. These two antennas are tested individually.
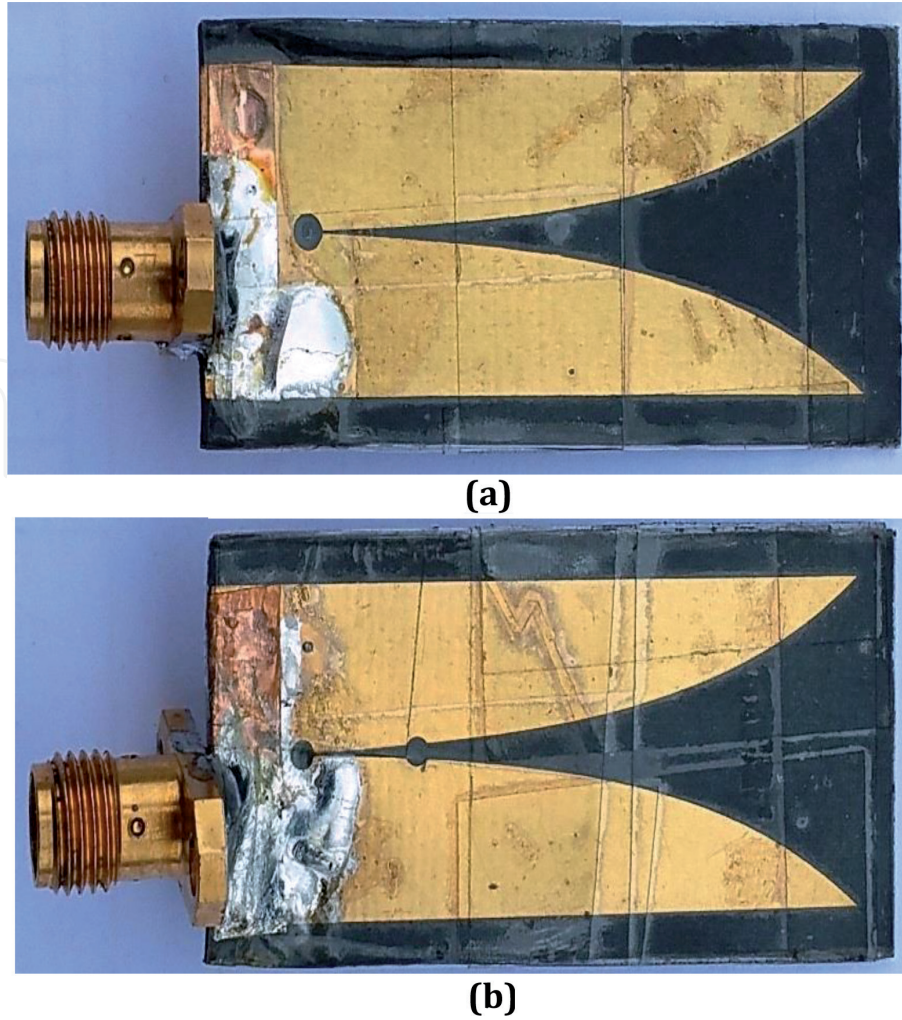
Figure 6.
(a) Fabricated single cavity Vivaldi antenna and (b) fabricated double cavity Vivaldi antenna.

4. Results

4.1 VSWR

The numerical simulation of directional antenna is done using CST software. The performance of the antenna does not improve monotonically as the parameters of the antenna changes. It must be optimized through analysis during simulation to get the optimum parameters.

The simulations for Vivaldi antenna operating in the band 8–18 GHz are done using CST. The obtained VSWR simulation results for the respective antenna are as shown in **Figure 7(a)** and **(b)**.

As shown in **Figure 7(a)** and **(b)**, the VSWR-frequency plot for the Vivaldi antenna without SMA connector seems to have a high VSWR, which means the reflection of power is more and the reflected wave amplitude is high from frequency 8 to 18 GHz.

To lower the VSWR, a connector is attached to the antenna for the required band of frequencies. **Figure 8(a)** and **(b)** shows the VSWR with SMA connector in CST software for single cavity and double cavity respectively.

4.2 Return loss

The obtained return loss simulation results for the single cavity Vivaldi antenna and double cavity Vivaldi antenna are as shown in **Figure 9(a)** and **(b)**, respectively.
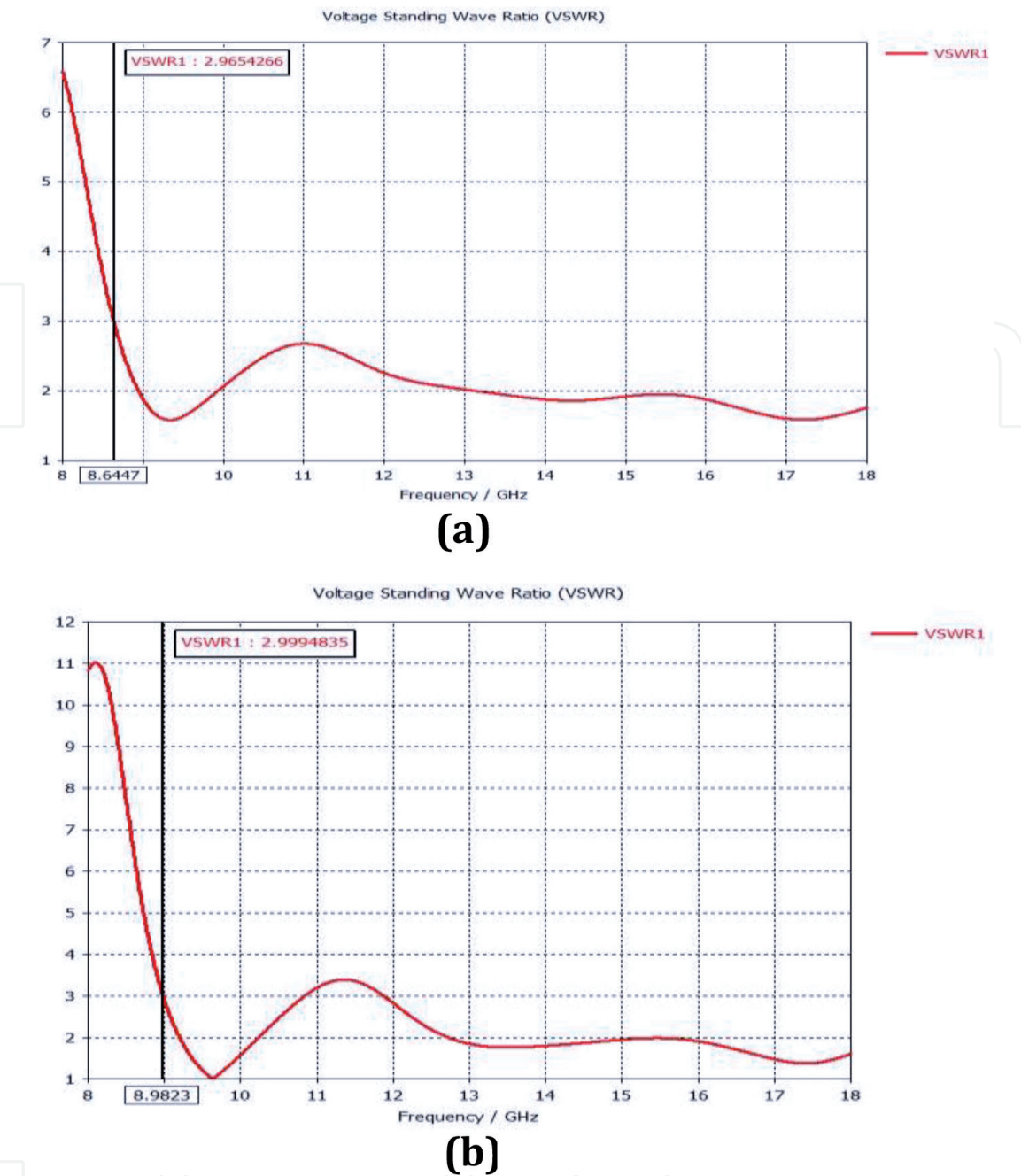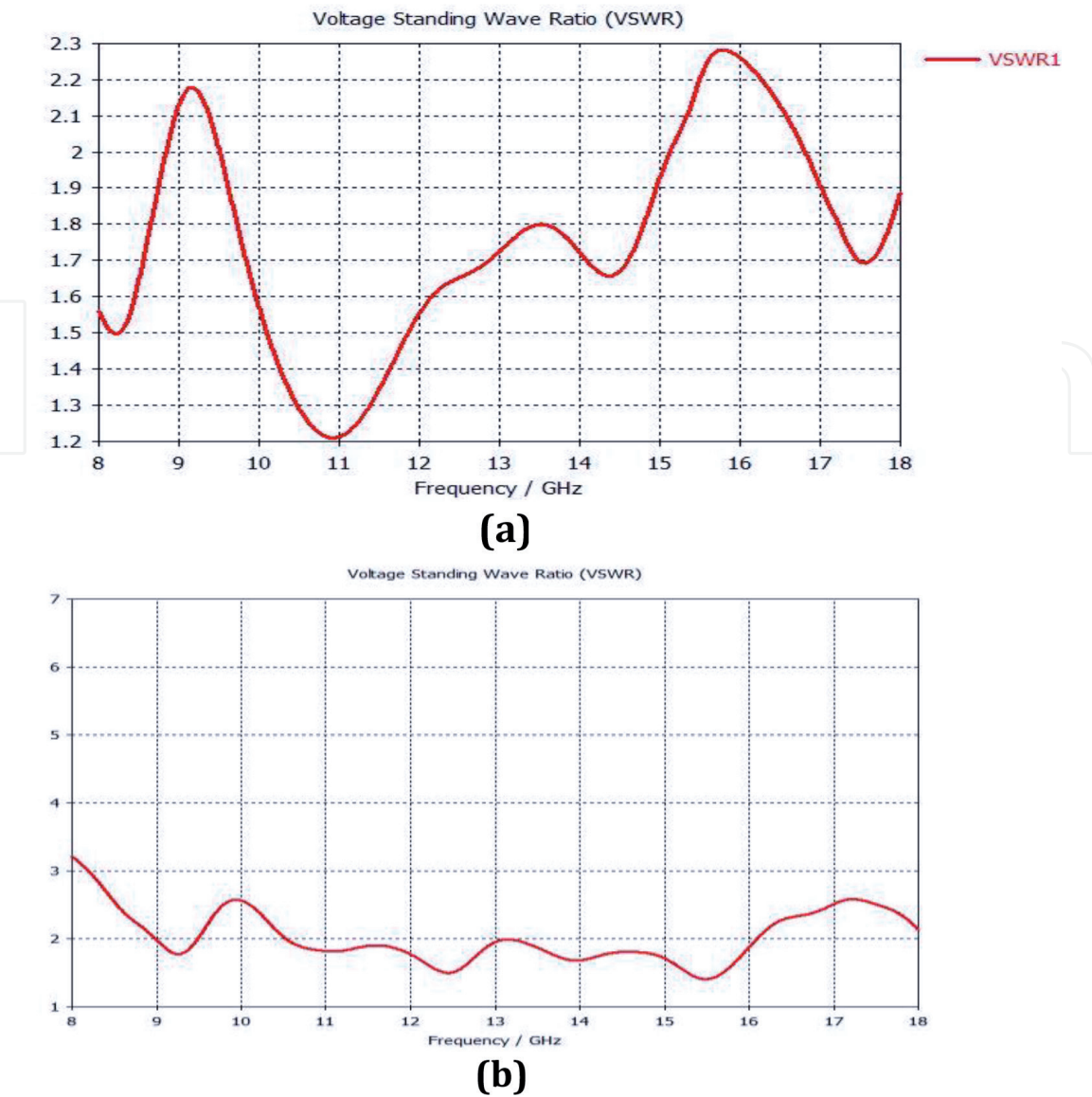
Figure 7.
(a) Simulated VSWR for single cavity Vivaldi antenna without SMA connector and (b) simulated VSWR for double cavity Vivaldi antenna without SMA connector.

Usually the return loss is the loss of power in the signal that is returned/reflected by a discontinuity in a transmission line. A minor discontinuity can be observed with the terminating load or with a device inserted in the line.

Practically, VSWR for the desired band of frequencies is measured using a network analyzer. The VSWR of the proposed antenna was measured using Agilent ENA series Vector Network Analyzer (VNA) E5071C and was found to be less than 3:1 throughout the desired frequency band.

The measured VSWR for single cavity antenna and double cavity Vivaldi antenna are shown in **Figure 10(a)** and **(b)**, respectively.

4.3 Return loss measurement

This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB).

(a)

(b)

Figure 8.
(a) Simulated VSWR for single cavity Vivaldi antenna with SMA connector and (b) simulated VSWR for double cavity Vivaldi antenna with SMA connector.
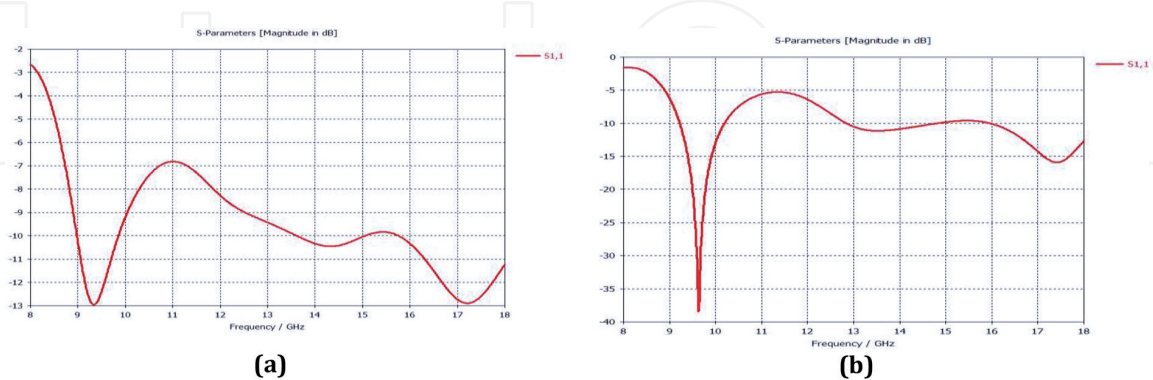

Figure 9.
(a) Simulated return loss for single cavity Vivaldi antenna and (b) simulated return loss for double cavity Vivaldi antenna.

The steps involved for measuring the return loss using network analyzer are given below:

1. select sweep frequency range by selecting start and stop frequency;

2. select one port S_{11} for calibration measurement;

3. select log amplitude mode on display;

4. calibrate the network analyzer by connecting the standard short circuit, open circuit and matched loads at the test port. Observe the trace on the display to get a solid reference line; and

5. remove the standards and connect the antenna and observe the shift in the trace of the display. The display can be changed for obtaining the return loss, reflection coefficient, and impedance over the selected frequency band.

Return loss in dB = −20 log (ρ), where ρ is the reflection coefficient.

The measured return loss for single cavity Vivaldi antenna and double cavity Vivaldi antenna are shown in **Figure 11(a)** and **(b)**, respectively.

4.4 Anechoic chamber

To provide a controlled environment, an all-weather capability, and security, and to minimize electromagnetic interference, indoor anechoic chambers have been developed as an alternative to outdoor testing. By this method, the testing is performed inside a chamber having walls that are covered with RF absorbers. The design of each is based on geometrical optics techniques, and each attempt to reduce or to minimize specular reflections. The phase difference between the
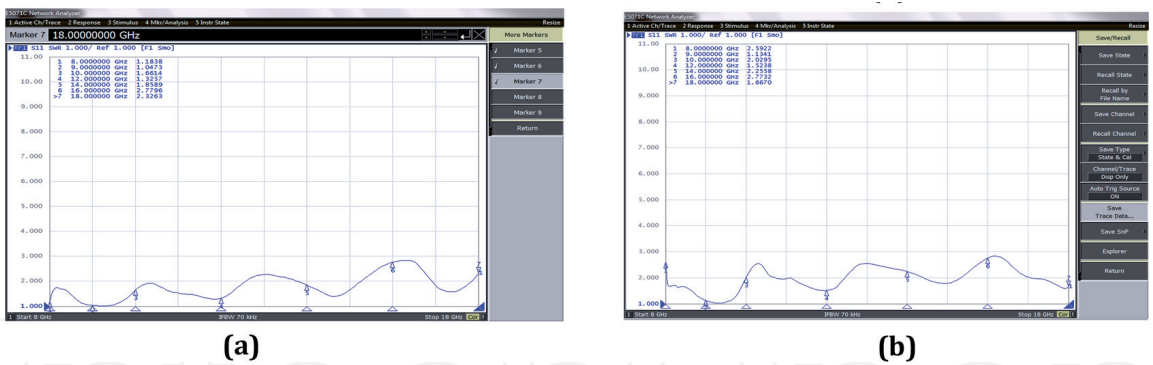

(a)   **(b)**

Figure 10.
(a) Measured VSWR for single cavity Vivaldi antenna and (b) measured VSWR for double cavity Vivaldi antenna.
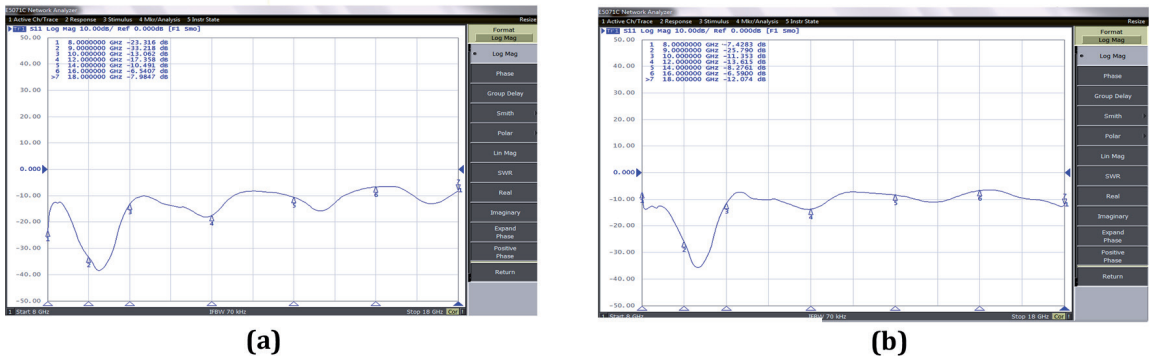

(a)   **(b)**

Figure 11.
(a) Measured return loss for single cavity Vivaldi antenna and (b) measured return loss for double cavity Vivaldi antenna.

Figure 12.
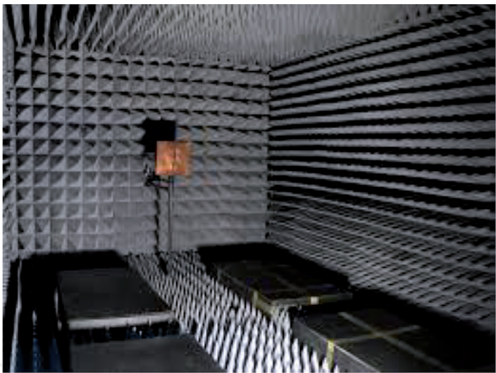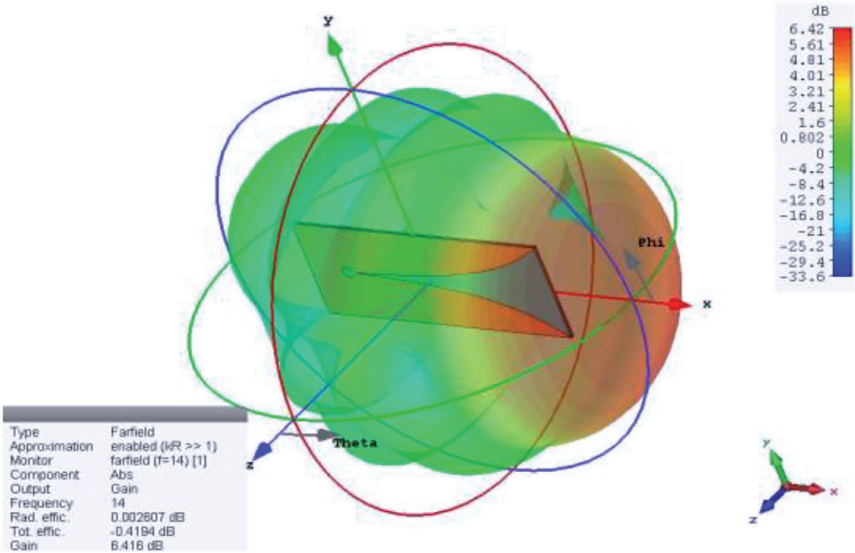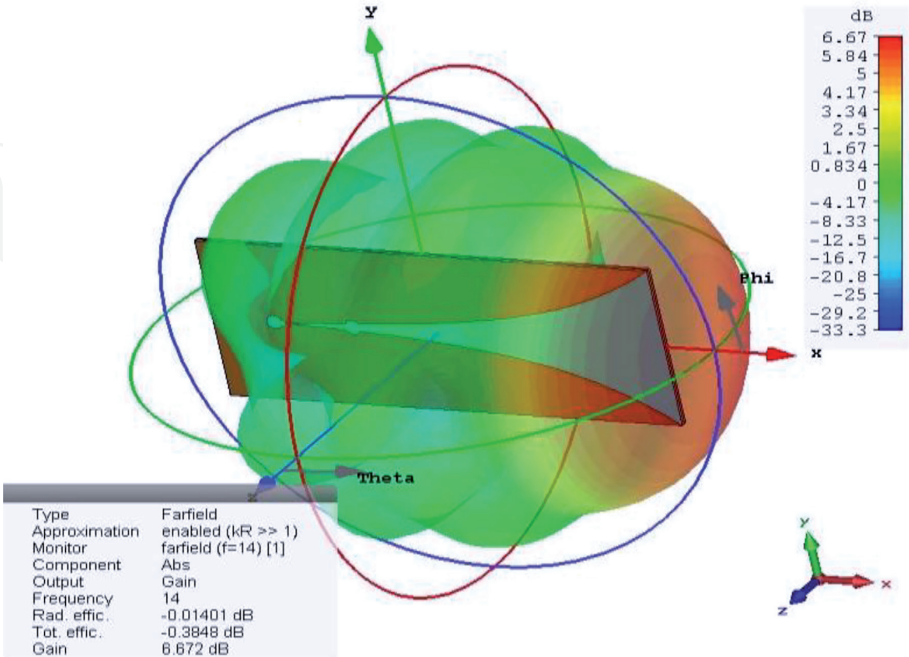*Anechoic chamber.*

(a)

(b)

Figure 13.
(a) 3-D radiation pattern of single cavity Vivaldi antenna at 14 GHz and (b) 3-D radiation pattern of double cavity Vivaldi antenna at 14 GHz.

direct radiation and that reflected from the walls near the source can be made very small by properly locating the source antenna near the apex. Thus, the direct and reflected rays near the test antenna region add vectorially and provide a relatively smooth amplitude illumination taper. This can be illustrated by ray-tracing techniques (**Figure 12**).

4.5 Radiation pattern

The simulated 3D radiation patterns of printed Vivaldi antenna for single cavity and double cavity at frequency of 14 GHz is shown in **Figure 13(a)** and **(b)** respectively.

4.6 Plane patterns

The E-plane and H-plane are the reference planes for linearly polarized waveguides, antennas and other microwave devices. The E-plane and H-plane patterns are also called as the polar plots or gain plots.

4.6.1 E-plane

The plane containing the E aperture and the direction of maximum radiation results in a linearly polarized antenna and it determines the orientation of the radio
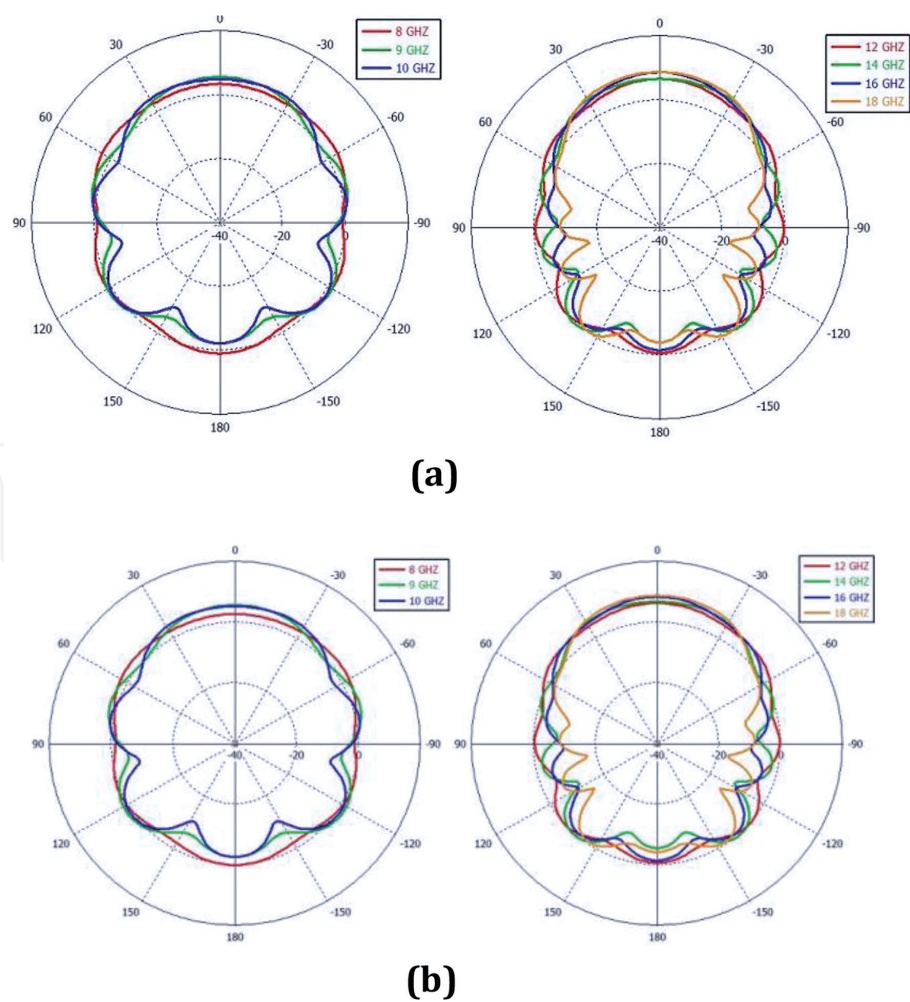

(a)

(b)

Figure 14.
(a) E plane patterns for single cavity Vivaldi antenna and (b) E plane patterns for double cavity Vivaldi antenna.

wave. The E-plane (XY-plane at θ = 90°) radiation patterns at different frequencies from 8 to 18 GHz for single cavity and double cavity are as shown in **Figure 14(a)** and **(b)**, respectively.

4.6.2 H-plane

The plane containing the magnetic field vector is referred as the H aperture and the direction of maximum radiation. The "H" plane lies at a right angle to the "E" plane. The H-plane (ZX-plane at φ = 0°) radiation patterns at different frequencies from 8 to 18 GHz for single cavity and double cavity are as shown in **Figure 15(a)** and **(b)**, respectively.

4.7 Gain of the antenna

The method used for the gain measurement of the antenna is gain-transfer method. In this technique the standard gain antenna which is known is used to determine the test antenna. Initially relative gain measurements are performed, which when compared with the known gain of the standard antenna gives the
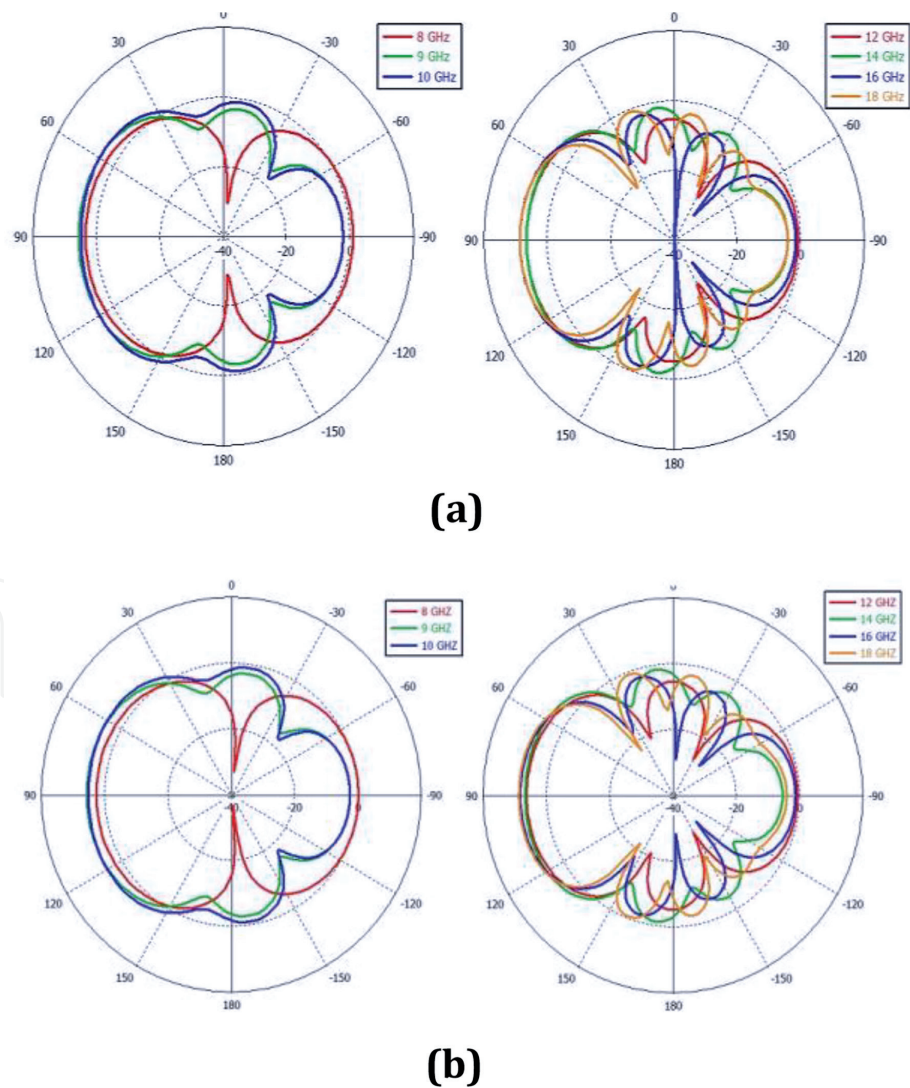

(a)

(b)

Figure 15.
(a) H plane patterns for single cavity Vivaldi antenna and (b) H plane patterns for double cavity Vivaldi antenna.

absolute values. The simulated gain of single cavity Vivaldi antenna varies from 3.36 to 8.55 dBi over the design frequency band as shown in **Figure 16(a)**. The simulated gain of double cavity Vivaldi antenna varies from 2.62 to 8.65 dBi over the design frequency band as shown in **Figure 16(b)**.

For measuring the gain of the antenna under test (AUT), formula is given by

$$\text{Gain of AUT (dB)} = \text{antenna power (dB)} - \text{reference antenna power (dB)} + \text{gain (reference antenna)} \tag{2}$$

The measured gain plots of single cavity Vivaldi antenna and double cavity Vivaldi antenna are shown in **Figure 17(a)** and **(b)**, respectively.

Finally, single cavity Vivaldi antenna gives the efficient impedance bandwidth than the double cavity Vivaldi antenna.

(a)

(b)
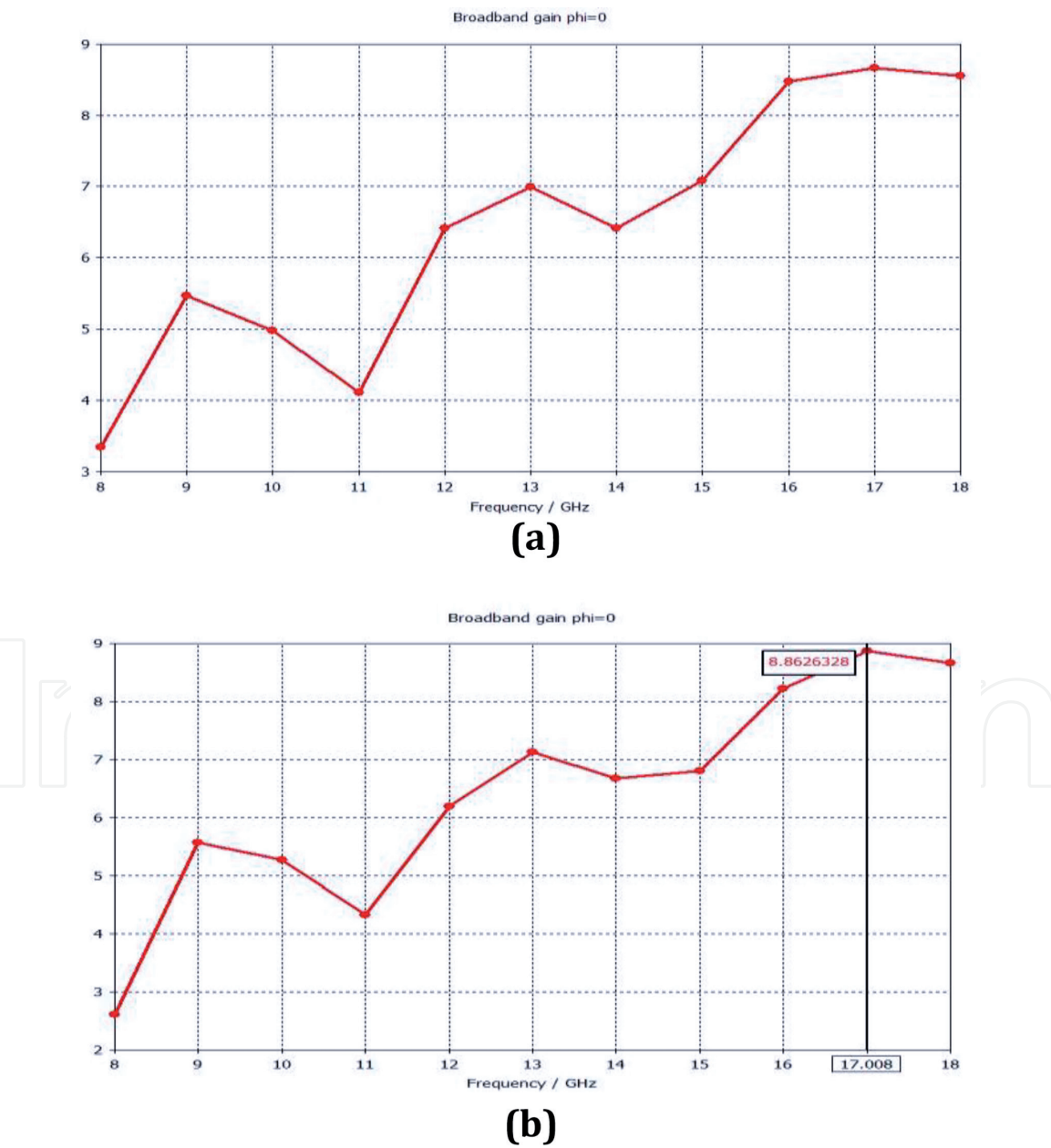
Figure 16.
(a) Simulated gain plot of single cavity Vivaldi antenna and (b) simulated gain plot of double cavity Vivaldi antenna.
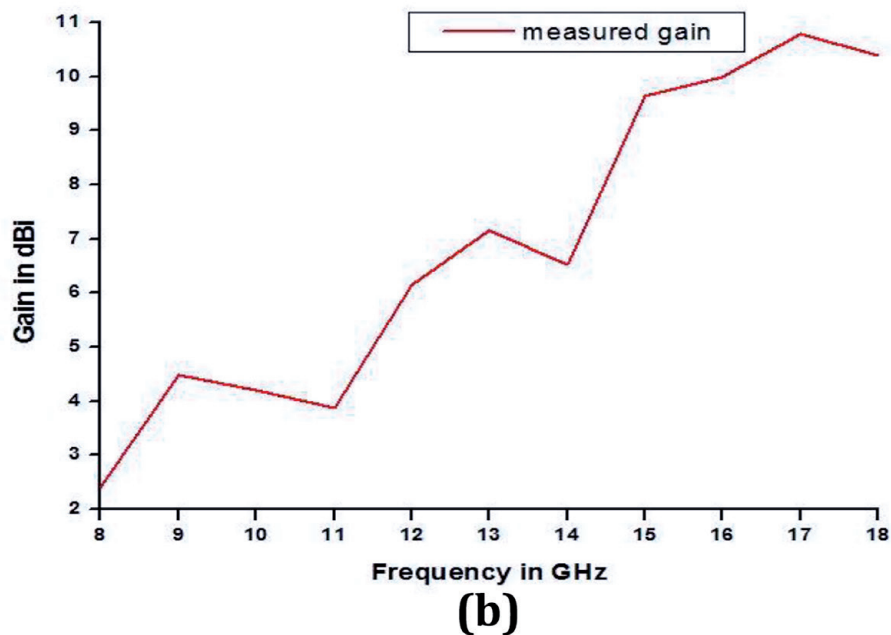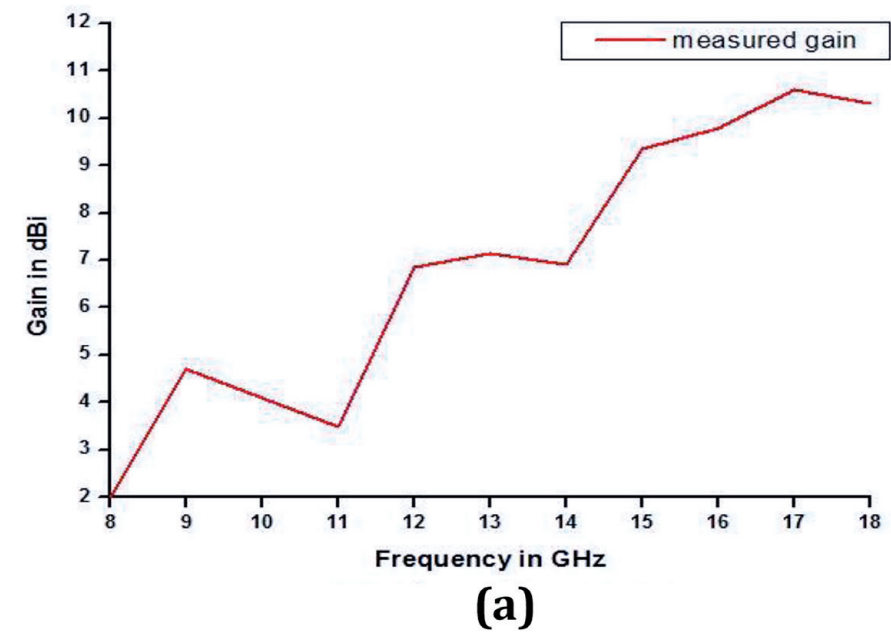
Figure 17.
(a) Measured gain plot of single cavity Vivaldi antenna and (b) measured gain plot of double cavity Vivaldi antenna.

5. Conclusion

The comparison of antenna performance for single cavity Vivaldi antenna and double cavity Vivaldi antenna are reported. The single cavity and double cavity have same performances, but single cavity gives efficient impedance bandwidth than the double cavity. The gain of double cavity is better than single cavity at higher frequencies and antenna miniaturization also possible.

The simulated and measured results of the proposed antenna were compared and found to be in good agreement. The optimum performance of the antenna in simulation is obtained by using parametric analysis. VSWR less than 3:1 is achieved over the band from 8 to 18 GHz. The antenna due to its compactness and light-weight serves its applications in radio communications, avionics, spectrum monitoring and military system. It also finds applications in digital data transmission via satellites and for voice/audio transmissions.

Acknowledgements

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